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INFRARED EMISSIVITY MEASUREMENTS AND ANALYSIS

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AND
JAMES R. BOWSER, JR.

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by

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and

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Captain, United States Marine Corps

Submitted in partial fulfillment of
the requirements for the degree of

MASTER OF SCIENCE

IN

PHYSICS

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ABSTRACT

Employing the Perkin Elmer Model 13 Ratio Recording Infrared Spectrophotometer, located in Spanagel Hall, U.S. Naval Postgraduate School, measurements were made comparing the emissivity of various building material samples to that of a black body, at 100°C. Correlation of this data was then undertaken to determine the level of the total radiant emittance of certain of these materials through the atmosphere and; the general characteristics required of a detector to properly survey a structure composed of these materials against contrasting background radiation.

The writers wish to express their deep appreciation for the assistance and guidance given by Professor Sydney H. Kalmbach, of the U. S. Naval Postgraduate School, throughout this investigation. Also, the writers wish to acknowledge the labor and technical assistance rendered by Chief Opticalman A. N. Goodal, U. S. Navy, in the fabrication of the varied equipment employed in this work.

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Symbol	Definition
c	Speed of light in a vacuum
h	Planck's constant
λ	Wavelength
k	Boltzsmann's constant
T	Absolute temperature of emitting surface
W_λ	Spectral radiant emittance per unit wavelength
W	Total radiant emittance for an interval of wavelengths
We	Total radiant emittance of a non-black body emitter(We = e.W).
W_T	Total radiant emittance transmitted (no absorption)
e	Emissivity (The ratio of radiant emittance of body to that of a black body at the same temperature.)
ω	Diameter of receiver or detector lens
L	Path length between emitter and detector
f	Focal length of detector lens
f No.	f number (Equal to $\frac{f}{\omega}$)
Cr	Apparent contrast
Co	Inherent contrast
R	Range in kilometers
Br	Structural radiant emittance at range R
Br'	Background radiant emittance at range R
Bo	Structural radiant emittance (Inherent)
Bo'	Background radiant emittance (Inherent)
σ	Attenuation coefficient (km^{-1})

Symbol	Definition
ln	Natural logarithm
Ieff	Sensitivity limit
τ_D	Response time
μ	Microns (10^{-4} cm)

1. Introduction.

The ever increasing usage of Infrared in military applications was the incentive for the writers to choose this field for thesis work. From available reference material, it was found that emphasis in the region of surface temperatures below $100^{\circ}C$ had not been fully exploited; therefore a study was contemplated in the near ambient range. A three-fold program of objectives in this investigation was proposed as follows:

a) To obtain emissivity measurements of various building materials at ambient surface temperatures.

b) From these measurements, determine the total radiant emittance of an average size building, constructed of some of these materials, under normal atmospheric conditions.

c) Finally, from the above results, to specify the general characteristics required of a detector to properly survey such a structure against interfering background radiation.

2. Experimental Equipment.

For descriptive purposes the experimental equipment employed, exclusive of the Perkin Elmer Spectrophotometer, may be divided into three catagories:

Part a. The Black Body and the associated control circuit.

Part b. The Sample Furnace and associated control circuit.

Part c. The Supplementary Optical System.

These items were designed and manufactured to obtain optimum use of the materials available and in conjunction with the basic unit, the spectrophotometer, provide a well integrated system.

a) Black Body.

Guided by the basic principle of a black body, that it be a perfect radiator and absorber, a choice of two forms became apparent, spherical cavity or conical cavity. Due to the inherent difficulty of drilling a spherical cavity, a conical cavity was chosen. The design used, as shown schematically in Figure 1, is described in a recent IRIS Report as an "Eppley Double Reversed Conical Cavity".[2]

Copper was chosen as the basic material of the black body because of its high thermal conductivity which therefore assures an even temperature distribution throughout the body. Essentially the black body itself was made by turning a solid copper cylinder on a lathe to provide the joint flanges, bisecting the cylinder through the flange section, and drilling a conical cavity into both halves. The cavity in one half was opened to the outside through a slit two

[2] IRIS Report Vol. 1, No. 1, pp. 39

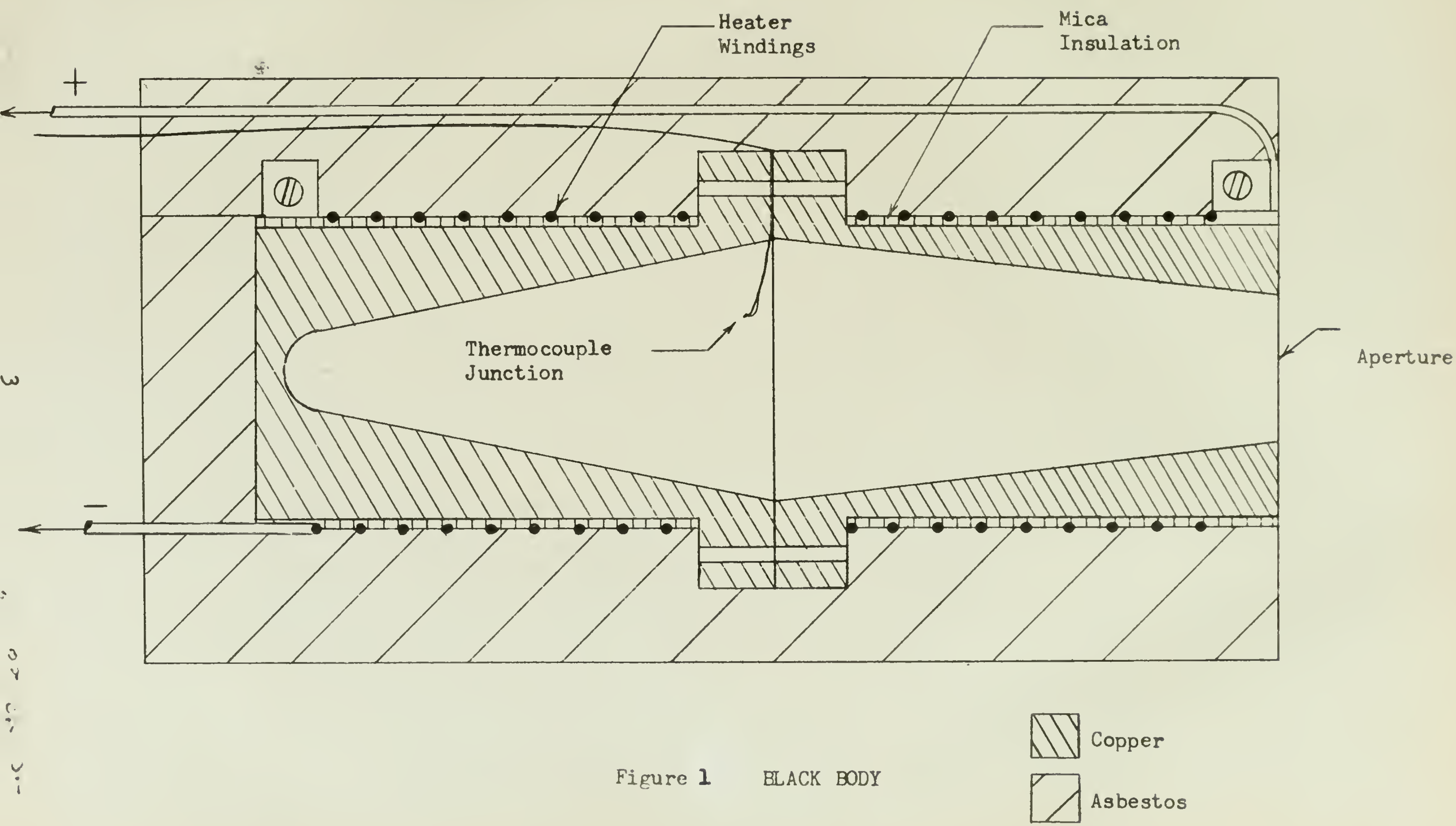

Figure 1 BLACK BODY

millimeters wide and one half inch long. The two halves were then rejoined and secured by four small screws in the flange section. The entire body was then blackened by placing it in a blueing solution of ebenol and maintained at 215°F for a 24 hour period. This proved to be a satisfactory method for blackening the surfaces.

In keeping with the objective of the investigation, i.e.; to study materials at or near ambient temperature, an elaborate heating system was not required. However, for positive temperature control, a means of elevating the temperature slightly above ambient and maintaining a steady temperature, was desirable. This was accomplished by wrapping the cylindrical ends of the black body with an insulating sheet of mica, over which approximately 20 turns of nichrome wire were wound and banded on each end of the cylindrical extensions. The entire unit was then wrapped in an asbestos covering to a uniform outside diameter of two inches. The reason for this will be evident in the discussion of the supplementary optical system.

Temperature measurement of the inside of the cavity was facilitated by a copper-constantan thermocouple inserted into the cavity through the flange section. (See Figures1 and 2). The thermocouple lead and the two ends of the heating element windings were drawn aft from the slit opening for the required junctures, and properly insulated.

Figure 2 shows the actual black body used, the windings, and the thermocouple junction.

The heating element was controlled by a D-C power circuit, employing a rheostat, as shown in Figure 5. A D-C ammeter was used to correlate current and temperature for finer control. A potential of 26V D-C and a maximum of 1 ampere proved more than adequate to maintain the temperature at which data was recorded.

Figure 2. Black Body

b) Sample Furnace and Control System.

The obvious requirement for a means of maintaining the sample material at the same temperature as the black body was fulfilled by the sample furnace.

Three uniform rings of 3/4 inch asbestos composition were secured together by brass screws. Two of the adjoining sections had a square hole cut in the center 7/8 inch by 1 inch to accept the samples. The third section, acting as a back wall of the furnace, was drilled with a small access hole for the thermocouple lead (see Figure 3). The entire assembly was then wound with nichrome wire as a heating element. A thin mica sheet, several wrappings of glass fibre cloth, and a layer of asbestos encased the furnace and windings. Like the black body, the outside diameter of the complete unit was two inches.

A copper-constantan thermocouple was used for temperature determination. A D-C power source identical to that of the black body served for temperature control.

The interchangeability incorporated in the design of the black body and furnace systems proved most advantageous in the final procedure employed for collecting data.

c) Supplementary Optical System.

The design of an adequate optical system to introduce radiation into the optical path of the spectrophotometer proved to be one of the more challenging aspects of this entire project. Several trial setups proved inadequate primarily due to the failure to introduce sufficient energy to meet the minimum response requirements of the spectrophotometer detector.

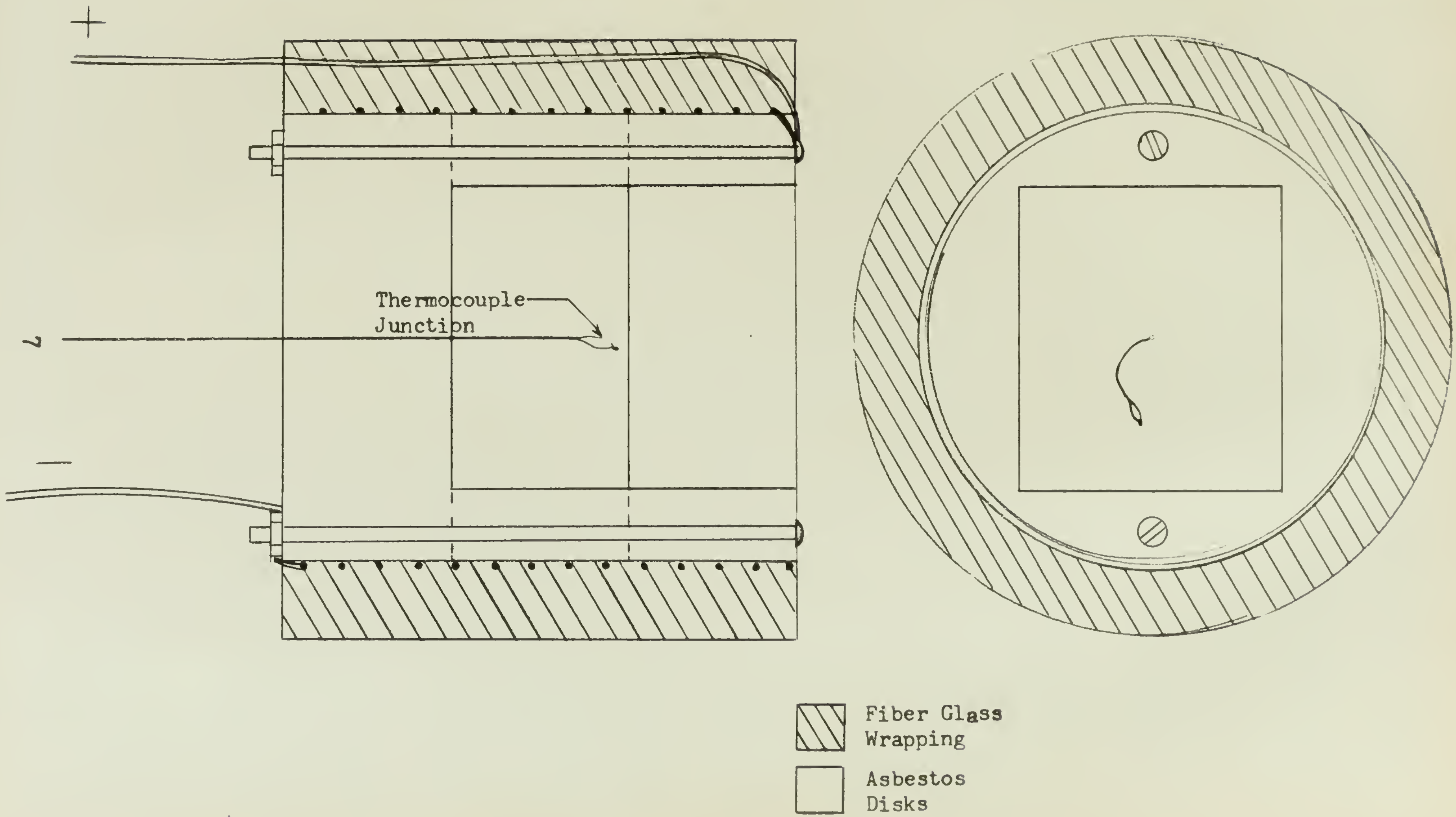

Figure 3 Sample Furnace

An acceptable design involved essentially a twofold problem:

(1) Elimination of all stray radiation from the radiation incident on the detector.

(2) Assurance that all of the radiation emanating from the sample surface was incident on the detector.

Phase one of the twofold problem was solved simply by a system of limiting apertures and slits, principally incorporated in the spectrophotometer itself. A pseudo-Cassegrainian mirror combination provided the solution to the second part. An ellipsoidal mirror 30 cm. in diameter mounted in conjunction with a plane mirror 10 cm. in diameter was employed. The actual system used was that salvaged from an outmoded infrared receiver, a schematic of which appears in Figure 4.

The black body or sample was placed at one focal point and the entire system adjusted such that the convergence of the beam was coincident with that required in the spectrophotometer. This particular adjustment proved quite tedious and time consuming in order to insure optimum use of all mirror surfaces and proper focusing.

Initially two receiving units were salvaged to provide one for the black body and one for the sample as shown in Figure 4. Path A required the use of a diagonal mirror for entry due to space limitations.

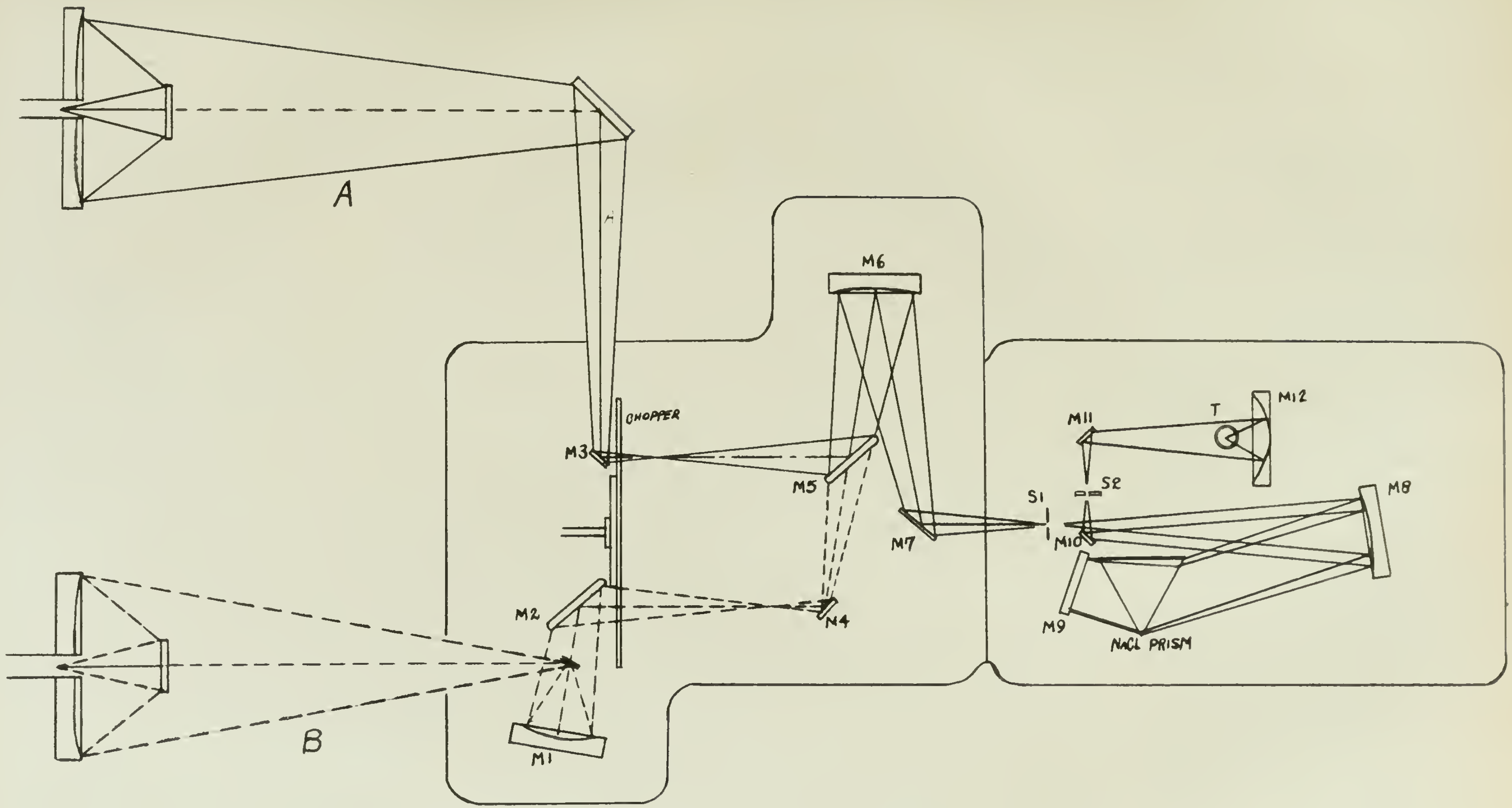

Figure 4   Overall Optical System

As previously mentioned, the black body and the sample furnace were both designed with the same outside diameter. These fitted snugly into the photo tube receptacle of the infrared receiver, placing the radiating source at the focal point of the mirror. This permitted unimpeded interchange of the two between path A and path B, without rearrangement of the optics.

3. Equipment Arrangement.

The overall arrangement of the apparatus is shown in Figure 6.

Mounted on one table was the monochromator and detector unit of the spectrophotometer and the supplementary optical system. Once the supplementary optical system had been properly aligned, the units were securely mounted in place with a beeswax-resin compound. Slits S1 and S2, in the spectrophotometer, were adjusted to a width of two millimeters. A sodium chloride prism was employed in the monochromator section and calibrated to the wavelength drum of the spectrophotometer. Of the prisms available, the NaCl prism transmission properties were most desirable for the wavelength region studied.

The detector element was a thermocouple. Adjacent to the main system stood the recorder element and accompanying equipment circuitry, visible on the right in Figure 6.

All of the control circuitry was mounted on an adjacent table. This included the thermocouple ice bath, potentiometer and switching device, heater element rheostats and ammeters.

It was originally intended to use both path A and B simultaneously with the black body in one receptacle and the sample in the other. The spectrophotometer would then directly record the ratio of the radiances. However, to check the continuity of the two paths, the black body radiation was recorded directly, first through path A and then path B. The energy loss in path B proved to be too severe to afford a valid comparison between the two paths. Correction of this defect would have involved replating and replacement of mirrors and complete realignment. Due to time limitations and the desire for uniform comparisons, path B

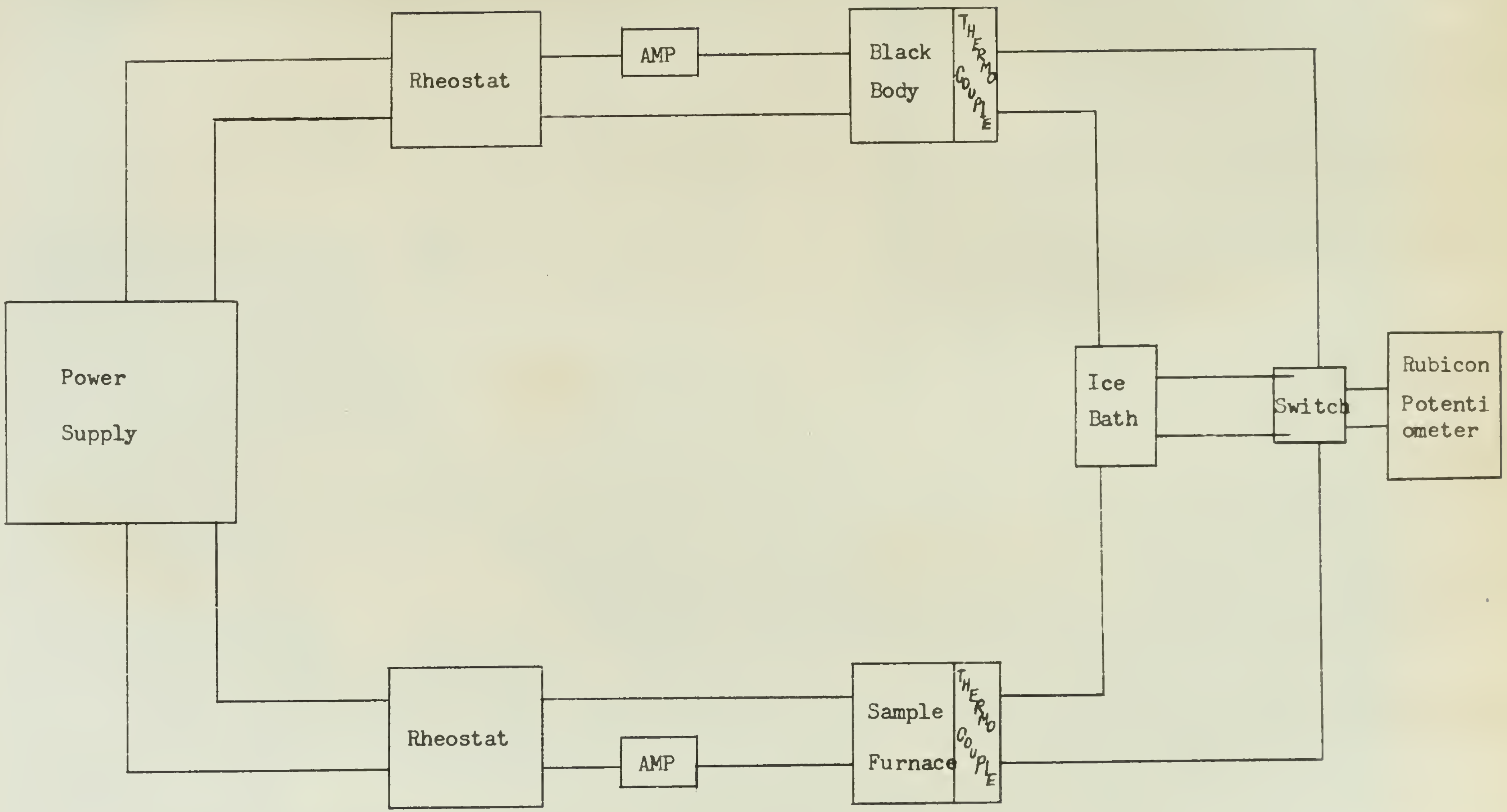

Figure 5 Circuitry Arrangement

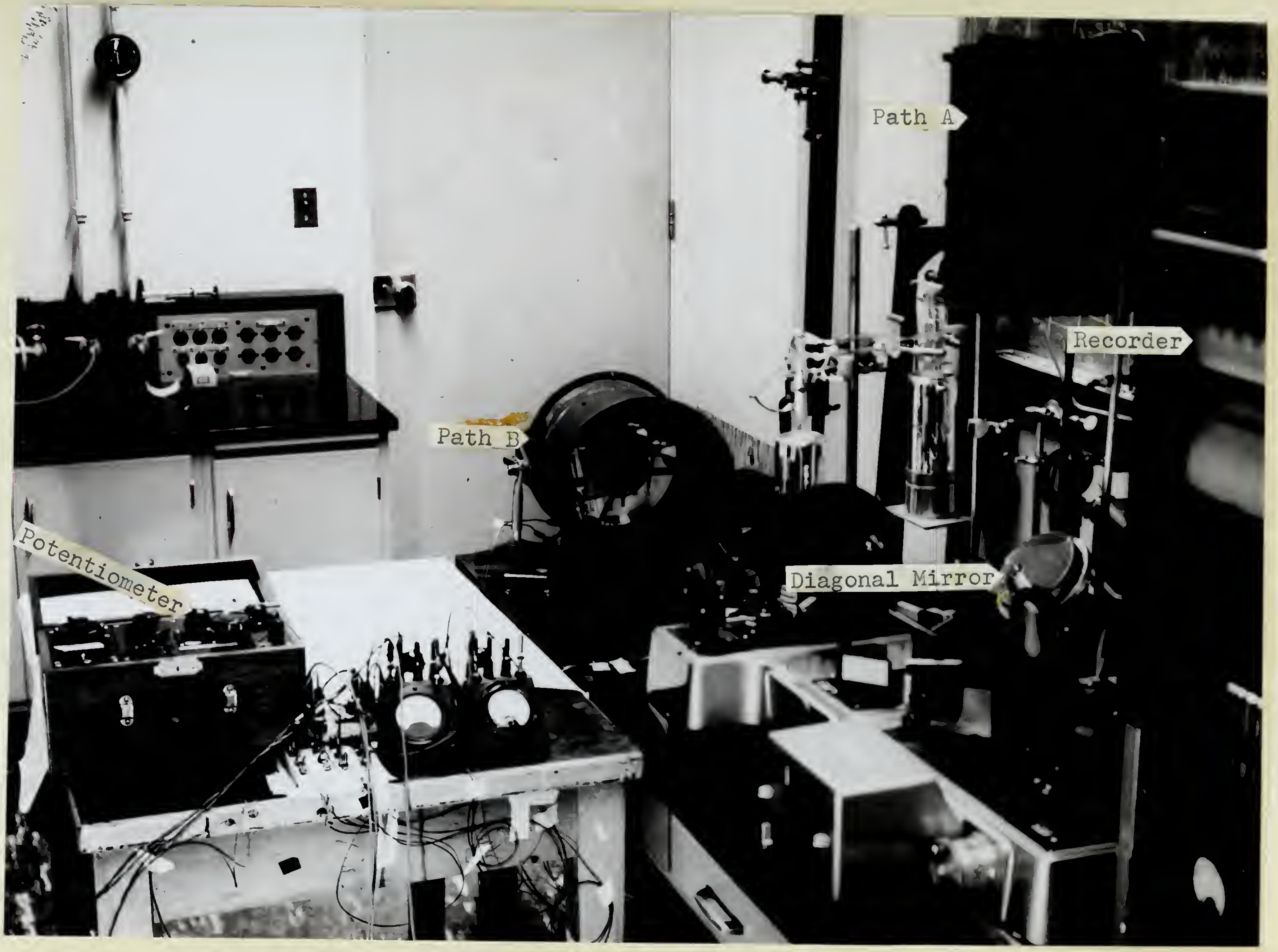

Figure 6 Equipment Arrangement

was eliminated rather than attempting readjustment to conform with path A measurements. Consequently, the recorder was employed in a direct reading mode using path A for the black body calibration curve and subsequent curves of sample radiant emittance.

One other modification to the system was required. During the runs to check uniformity of paths A and B, it became apparent that the radiation received at the detector was not conforming to that predicted for black body radiation. It was then concluded that the limiting aperture of the two millimeter slit width in the face of the body did not present enough of the true radiation. The radiation actually measured was considered primarily that of the copper face surrounding the slit. The face of the black body was then drilled out to a circular aperture one half inch in diameter. Subsequent calibration gave the desired results corroborating the foregoing assumption.

4. Experimental Procedures.

As contemplated in the three-fold objectives outlined in the introduction, the writers desired to obtain the emissivity measurements at true ambient conditions, which was considered to be in the 25^{o} to $30^{o}C$ range. However, because of apparent losses of radiant energy in the optical path employed and, too, the requirement for such high amplifier gain in order to obtain significant readings, a modification to this objective was necessitated. Due to the inconclusive results in the aforementioned temperature range, successive trials were made in 25^{o} steps up to $150^{o}C$ to obtain the optimum temperature for comparison purposes. It was found that $100^{o}C$ was the lowest temperature which afforded distinct and reliably consistent comparisons. Consequently, all data was taken at $100^{o}C$.

As previously noted, all comparisons were made employing the same optical path for both the black body and the samples. While this method necessitated additional labor in the compilation of results, it did ensure uniformity of these results. The following additional measures were also employed to maintain this uniformity:

a) Thermocouples were located, respectively, at the center of the black body cavity and touching the rear surface of the sample in the sample furnace.

b) Twenty minutes was allowed to slowly raise the black body and the samples to $100^{o}C$, with a five minute check thereafter to insure that this temperature was maintained.

c) Continuous checks of the black body and sample temperatures were made throughout the runs.

d) The complete optical path and mirror system were draped with black cloth to prevent possible stray radiations from entering the system. Further, only a desk lamp was permitted while recording.

e) The black body curve was run at the commencement and completion of each set of data to ensure uniformity. Also, zero checks of the instrument recorder were made during each run.

f) The relative humidity and temperature were, respectively, between 50 and 52% and 70° to $72^{\circ}F$ while making these observations.

Figure 7 represents the black body curve obtained during measurement at $100^{\circ}C$. This figure is not exact, but is enclosed merely to show the general appearance of the recorded black body curve. In general, this curve was also recorded for sample materials which showed definite responses, but, to varying degrees, reduced in amplitude. The high water vapor absorption centered at about 6 microns is clearly evident.

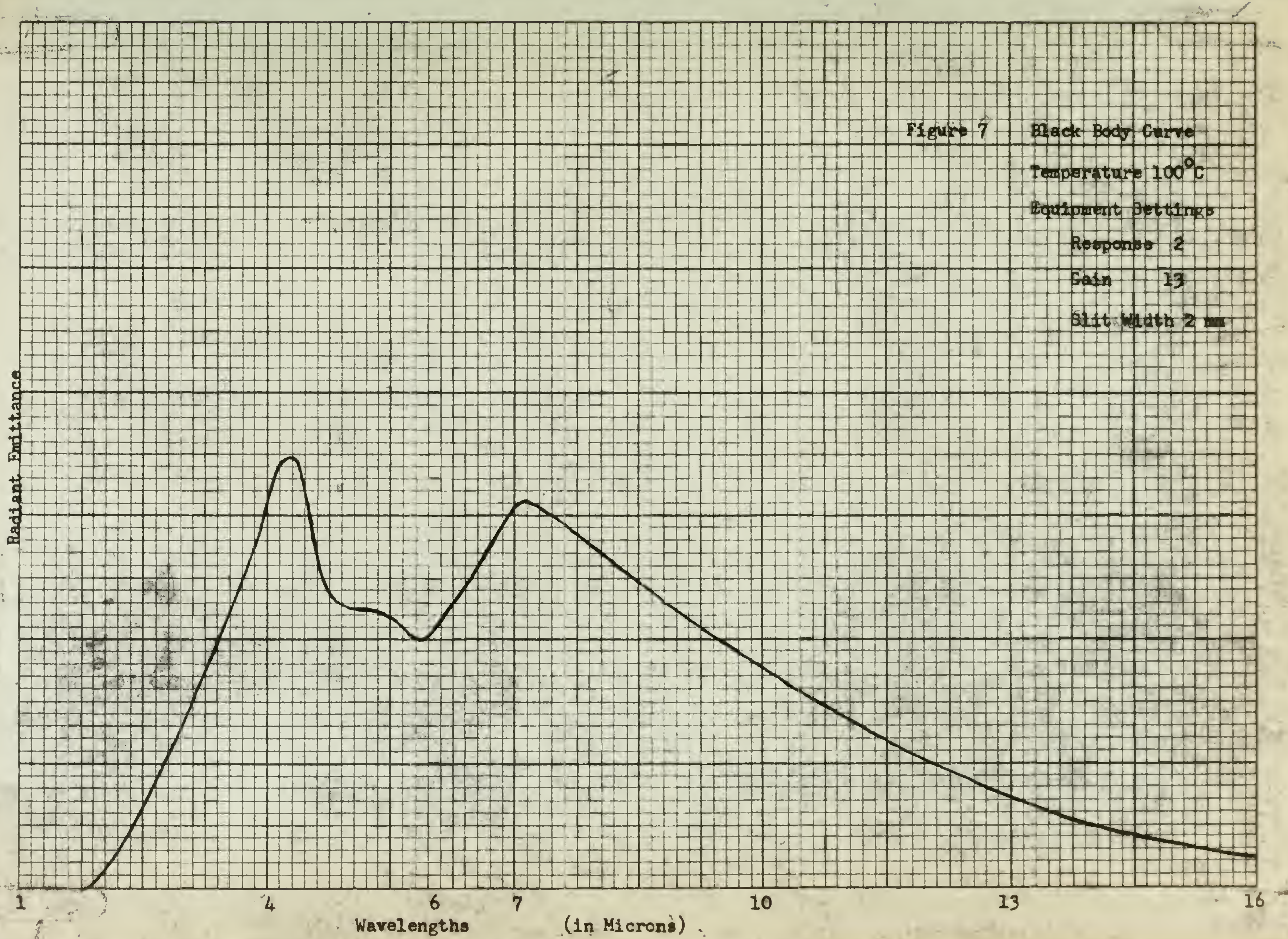
Figure 7
Black Body Curve
Temperature 100°C
Equipment Settings
Response 2
Gain 13
Slit Width 2 mm
Radiant Emittance
1
4
6
7
10
13
16
Wavelengths
(in Microns)

5. Experimental Results.

A summary of the emissivities of the samples (1" x 7/8") tested is as follows:

Sample	Thickness	Emissivity
a. Building Materials:		
Construction Brick	3/4"	.73
Red Brick	13/16"	.15
Chimney Brick	7/8"	.33
Tar Roofing	1/8"	.46
Red Cedar (shingle)	5/16"	.11
Douglas Fir (5 Ply)	3/4"	.28
Douglas Fir	3/4"	.21
White Pine	3/8"	.28
Redwood (Calif.)	7/8"	.15
Oak	11/16"	0 to .09
*Ponderosa Pine	3/4"	0
Insulation (Celotex, Impregnated and Non-Impregnated)	1/2"	.033
Asbestos	1/8"	.49
Plaster Board (Sheet Rock)	1/2"	.11 to .25
b. Paints:		
Synthetic Enamel (on White Pine)		.40
Gloss Enamel (on White Pine)		.36
*Fire Control Enamel (on Oak)		0
*Fire Control Enamel (on Douglas Fir)		0
*Black Enamel (on Oak)		0
*Black Enamel (on Douglas Fir)		0
*Yellow Lacquer (on Pine)		0

c. Metals (Commercial Grades):

*Copper (highly polished)	7/8"	0
*Brass (highly polished)	7/8"	0
*Aluminum (highly polished)	7/8"	0
*Steel (highly polished)	1"	0
⸘Steel (highly polished-Canted 35° to the normal)	1"	0 to .14

The above emissivity values were measured at the corresponding peak response point of the black body. In all cases, the peak response of the materials tested fell at a corresponding point or over a broad region in the vicinity of this black body peak.

*No perceptible response could be observed. In the case of the paints, it could be concluded that the lacquer and enamels, except the synthetic and gloss, actually result in a reduction of the emissivity of the materials tested. The synthetic and gloss enamels are a product of the Tracy Paint Company. (No information as to the bases used in these paints could be obtained).

⸘The change in the emissivity of the steel sample when tilted appears to be positive proof that the previous measurements were true emissivities. This contention is based on the fact that had the sample been faced normal to the radiance path of the system, reflectance from the sample would not have been transmitted through the system, but rather, reflected back to the sample due to the optical flat of the pseudo cassegrainian mirror system. However, on tilting, some reflectance from the surface of the sample could escape into the radiance pathway thereby giving an erroneous response.

6. Applications.

a) Assumptions

Before a solution can be derived in fulfillment of the second and third objectives outlined in the introduction, certain basic assumptions must be made as follows:

(1) That emissivities, as found above at 100°C, are essentially the same as would be obtained at ambient temperatures. This assumption is considered basically sound as this procedure is noted in similar analogies over broader temperature ranges by such authorities as W. E. Forsythe[11].

(2) That ambient temperature be considered as 27°C.

(3) That the radiation from the assumed structure be viewed in a horizontal plane and further, this radiation be due to the maximum exposed surface area of the structure.

(4) Standard atmospheric conditions exist.

b) Structural Emittance

The structure assumed is a typical three bedroom tract home, quite prevalent in the local Monterey area. The external composition, side dimensions, and percent emissivity contribution to the total emissivity for a floor area of 1680 square feet is estimated as follows:

Material	Area (ft^2)	% of Total Area	e	% of e to Total e
Chimney Brick	9	1.0	.33	.0033
Red Cedar (Shingles)	343	38.9	.11	.0428
White Pine (Doors, frames, etc. gloss enameled)	94	10.6	.36	.0395
Stucco (Construction Brick)	268	30.3	.73	.2210
Red Brick	144	16.2	.15	.0243
Glass[8]	24	3.0	.94	.0282
Totals	882			.3591

[8]Emissivity of glass from W. H. McAdams, "Heat Transmission", pp. 477, Table A-23.

c) Atmospheric Absorption and Transmittance.

In general it might be said that an enormous amount of work has been undertaken in this field, but the diversification of investigation makes correlation of these results indeed a formidable task. However when one considers the multitude of variables that enter into this field; i.e., solar and background radiation, atmospheric composition, temperature, etc., one begins to appreciate the requirement for such diversification. The Ohio State Research Foundation Reports,[14,16,17,] proved most valuable for our purposes as these investigations specifically covered the wave bands of interest, as to transmission and absorption of black body radiation at ambient temperatures and, too, background radiation studies at ambient temperatures.

It is noted that in the work of Nielsen and Shaw[17], in addition to the strong ozone absorption band previously reported at 9.6 μ, varying intensity absorption bands were also reported for CO_2 at 9.4 and 10.4 μ, Ethylene(C_2H_4) at 10.5 μ, and Ammonia (NH_3) at 10.5 μ. However, the effects of these constituents, particularly C_2H_4 and NH_3, were reportedly weak and the final conclusion was that 100 percent transmittance could be considered in the range of our interest 9.5 μ to 10.5 μ. Consequently, on this basis, the transmittance from the assumed structure, at a temperature of 27°C would be essentially the same as the transmittance through a vacuum.

To determine this transmittance, a spherically shaped body is assumed. Neglecting absorption, the radiant energy flux at the

focal point of a lens system of a detector would be:

$$W_T = \left[4\pi r^2 \cdot W_e\right]\left[\frac{\pi \omega^2}{4 \cdot 4\pi L^2}\right]\left[\frac{1}{\pi r^2} \cdot \frac{L^2}{f^2}\right]$$

Where

$4\pi r^2 \cdot W_e$ = Total radiant energy flux from the spherical body.

$\frac{\pi \omega^2}{16\pi L^2}$ = Ratio of solid angle subtended by the lens to the total solid angle at a distance L from the body.

$\frac{1}{\pi r^2} \cdot \frac{L^2}{f^2}$ = Reciprocal of the area of the image at the focal point of the lens.

This expression is applicable to our structure and reduces to:

$$W_T = \frac{W_e}{4\left(\frac{f^2}{\omega^2}\right)}$$

In order to specify the actual radiant emittance of this structure, the radiant emittance of a black body at the same temperature must be determined. Planck's Law of Radiation for a black body is:

$$W_\lambda = \frac{2\pi c^2 h}{\lambda^5\left[e^{\frac{ch}{\lambda k T}} - 1\right]}$$

Differentiating this expression and setting equal to zero, gives Wien's Displacement Law, an expression for the wavelength for maximum radiant emittance at a particular temperature. For a temperature of 27°C, this wavelength is:

$$\lambda_m = \frac{2897}{300} = 9.9\ \mu$$

To determine the total radiant emittance over a finite wavelength interval, say λ_1 to λ_2, involves an extremely complex integral. However, in anticipation of the inherent difficulties of maintaining a detector completely stable at one particular wavelength, for practical considerations a narrow wavelength interval should be specified. The selected interval was 9.5 to 10.5 microns and integration of the following integral was undertaken by graphical analysis:

$$W = \int_{\lambda_2}^{\lambda_1} W_\lambda \, d\lambda$$

Substituting the numerical values for the constants and for a temperature T=300°K, this integral becomes:

$$W = \int_{9.5}^{10.5} \frac{3.740 \times 10^4}{\lambda^5\left[e^{\frac{1.4385 \times 10^4}{\lambda(300)}} - 1\right]} \, d\lambda$$

The graphical solution yields a value of

$$W = 3.0992 \times 10^{-3} \text{ watts cm}^{-2}$$

Therefore, the total radiant emittance of the assumed structure would be:

$$W_e = e \cdot W$$

$$W_e = .359\,(3.0992) \text{ milliwatts cm}^{-2} = 1.113 \text{ milliwatts cm}^{-2}$$

Assuming an f No. of one, the radiant emittance received at a detector from the assumed structure would be:

$$W_T = \frac{1.113}{4} \text{ milliwatts cm}^{-2} = .2782 \text{ milliwatts cm}^{-2}$$

Data obtained from a report by Sloan[15], over a projected period of eight months, at Columbus, Ohio, gives the background radiance study for various times of day. A graph of this data for a wavelength range 9.25 to 10 μ (Figure 8), indicates very definite and significant levels of radiance based on time of day and seasonal variations. It is noted that hourly changes are very pronounced; i.e., the two circled high points were observations made at noon. Additionally, it is to be noted that the daylight observations fell off significantly during the winter months, which is assumed is to be due to the high reflectivity of snow, which probably existed during these observations. The average daylight background radiant emittance obtained from this study was .159 microwatts cm^{-2}.

The fundamental formula for contrast reduction by the atmosphere [4,18,19] for a line of sight directed horizontally is:

$$\frac{C_r}{C_o} = e^{-\sigma R} \qquad \text{where} \qquad C_r = \frac{B_r - B_r'}{B_r'}$$

$$C_o = \frac{B_o - B_o'}{B_o'}$$

Middleton[19] defines the terms B and B', subscripts r and o, in terms of luminous energy because of the need to consider the wavelength variation of stimulation of the eye. However, since the situation we faced assumed its present status with wavelength as the primary starting argument, the present units were considered satisfactory for comparison purposes.

[19] W.E.K. Middleton, "Vision Through the Atmosphere" pp. 7

Figure 8 Seasonal Period of Observation (1954)

Middleton[19] reproduces a set of graphs obtained by J. M. Waldram which show measurements of the photometric properties of the atmosphere. These graphs indicate an average value of the scattering coefficient of about 10^{-1} Km^{-1} for air in which absorption is negligible; hence the attenuation coefficient (σ) is also equal to this value.

Employing the value of the attenuation coefficient noted above, the range for an apparent contrast equal to two would be found in the following manner:

$$C_r = 2$$

$$\sigma = 10^{-1}\ km^{-1}$$

$$B_o' = .159 \times 10^{-3}\ \text{milliwatts cm}^{-2}$$ (the average daylight observation obtained from Figure 8)

$$B_o = .2782\ \text{milliwatts cm}^{-2}$$ (W_T value from page 25)

$$C_o = \frac{B_o - B_o'}{B_o'} = 1750$$

By the contrast reduction formula:

$$R = \frac{\ln C_o - \ln C_r}{\sigma}$$

$$R = \frac{7.46 - .693}{10^{-1}}\ km$$

$$R = 67.67\ km$$

[19] W.E.K. Middleton, "Vision Through the Atmosphere" pp. 47-50

d) Detector Characteristics.

In specification of detector characteristics the first consideration must be the intended purpose or usage of such a device. In the case being considered, the writers cannot envision any usage other than military applications such as for search or reconnaissance purposes. To accomplish this, the following basic representative parameters must be specified:

(1) The free aperture area (sensitive surface area): A 2mm x 2mm area is assumed.

(2) Response time (Time constant τ_D). Two different detector response times are assumed:
(a) 1 microsecond and (b) 1 millisecond.

(3) Spectral response region: 9.5 to 10.5 μ with peak response at 9.9 μ .

(4) Sensitivity limit (Ieff).

For an apparent contrast equal to two, as calculated in subparagraph c above, the radiant emittance of the assumed structure at the detector (Br) would be:

$$C_r = \frac{B_r - B_r'}{B_r'}$$

$$B_r = C_r B_r' + B_r'$$

$$B_r = \left[2 \times .159 + .159\right] 10^{-6} \text{ watts cm}^{-2}$$

$$B_r = 4.77 \times 10^{-7} \text{ watts cm}^{-2}$$

The sensitivity limit, as specified in units employed by R. J. Havens[1], for a cell one square millimeter in area would therefore be:

$$\tau_D = 10^{-6} \text{ secs.}$$

$$I_{eff} = B_r\left(\text{in } \frac{\text{watt}}{\text{cm}^2}\right) \times \text{Area}\left(\text{in cm}^2\right) \times \tau_D\left(\text{in secs}\right) \text{ Joules}$$

$$I_{eff} = 4.77 \times 10^{-7} \times 4 \times 10^{-2} \times 10^{-6} \text{ Joules}$$

$$I_{eff} = 1.908 \times 10^{-14} \text{ Joules}$$

This value falls considerably below the minimum detectable level of detectors currently available; however, for a detector response time of 1 millisecond, as noted below, the value obtained is within the minimum detectable level of available detectors:

$$\tau_D = 10^{-3} \text{ secs.}$$

$$I_{eff} = 1.908 \times 10^{-11} \text{ Joules}$$

[1] IRIS Report Vol. II No. I, pp. 5

7. Conclusions.

Upon completing this investigation the writers question the magnitude of the contribution of this brief study to the overall advancement of the knowledge and application of infrared. The intended objectives have been met and solved by the usage of our collected data and/or from the data and theories currently in existence; however, some of the theories and applications encountered, several of which were applied herein, were found to vary in the degree of acceptance by workers in the field. Not surprising, but disturbing!

Nevertheless there are certain basic facts which can be concluded from this study:

a) Emissivity and atmospheric transmittance measurements and analysis in the near ambient region has definitely been very limited. The emphasis appears to be in the high temperature regions, possibly due to a lack of suitable detectors for low temperature work.

b) Certain materials have no detectable radiant emittance (i.e., highly polished metals and ponderosa pine) whereas other materials either increase the radiant emittance of the basic material (i.e., gloss and lacquer on white pine) or reduce the emittance (i.e., fire control enamel and black paint on oak).

c) To provide a detector with a response time of 1 microsecond for usage as proposed in this article, requires a cell with a minimum sensitivity much lower than any presently known to the authors.

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